(12) UK Patent Application (19) GB (11) 2 188 719 (13) A

(43) Application published 7 Oct 1987

(21) Application No 8608029

(22) Date of filing 2 Apr 1986

(71) Applicant
STC plc

(Incorporated in United Kingdom)

10 Maltravers Street, London WC2R 3HA

(72) Inventors
Richard Edward Epworth
Roger John Brambley
David Franics Smith

(74) Agent and/or Address for Service
M. C. Dennis,
STC Patents, Edinburgh Way, Harlow, Essex CM20 2SH

(51) INT CL[4]
G02B 6/16 // G01L 1/24

(52) Domestic classification (Edition I):
G1A A5 CF DJ G7 P10 R7 T15 T20 T24 T5
B2E 1537 1726 415S 439S 563T 610T KD
C1M 400 401 BA
G2F 21P 23F 28C 28W CW
U1S 1915 2169 2208 B2E C1M G1A G2F

(56) Documents cited

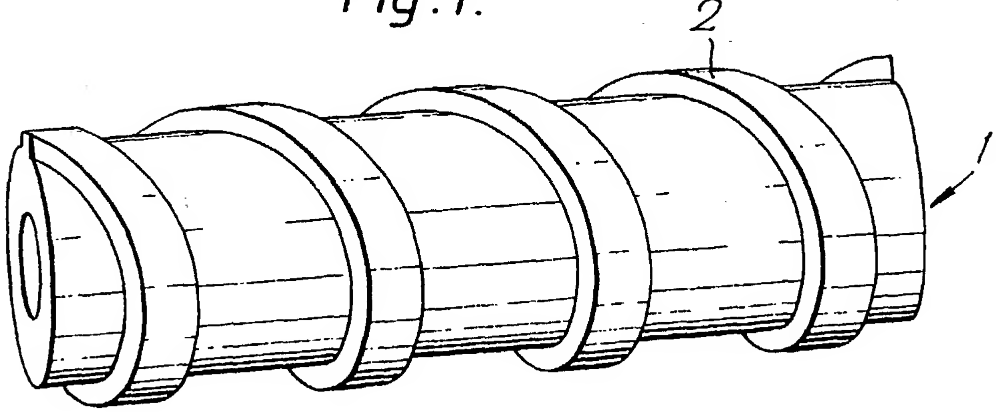
GB A 2162440	GB 1593868	EP A2 0082820
GB A 2058394	GB 1448080	US 4038062
GB A 2002536	GB 1339599	US 4028081

(58) Field of search
G1A
G2F
C1M
B2E
Selected US specifications from IPC sub-classes B05D C03B G01L G01N G02B G02F

(54) Optical fibres

(57) An optical fibre 1 includes a structure, for example as part of the fibre core structure or of a coating thereon, such that the deformation of the core structure (bending or pinching) required for optical power coupling between modes can be achieved simply by producing changes in the pressure pertaining across the fibre transversely to its length, such as by squeezing the fibre between two smooth surfaces or changing the fibre tension. The structure may include means extending helically or in a snake-like manner with respect to the length of the fibre. A helically extending means may be comprised by a helical rib (2) of the coating.

Fig. 1.



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The drawings originally filed were informal and the print here reproduced is taken from a later filed formal copy.

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Fig.1.

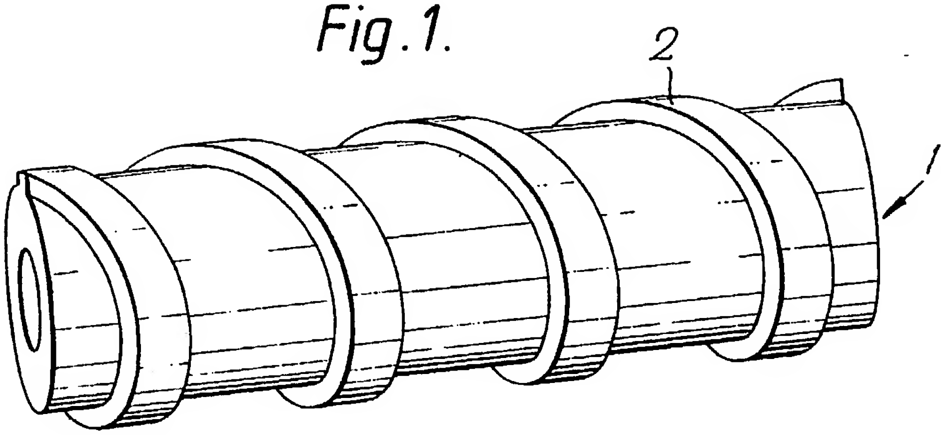


Fig.2a.

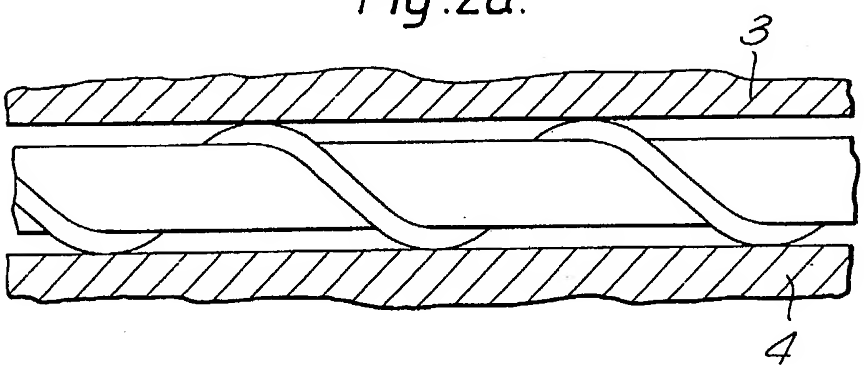


Fig.2b.

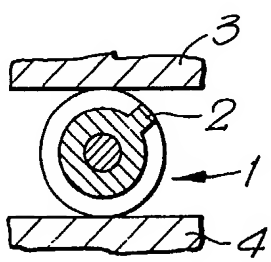


Fig.2c.

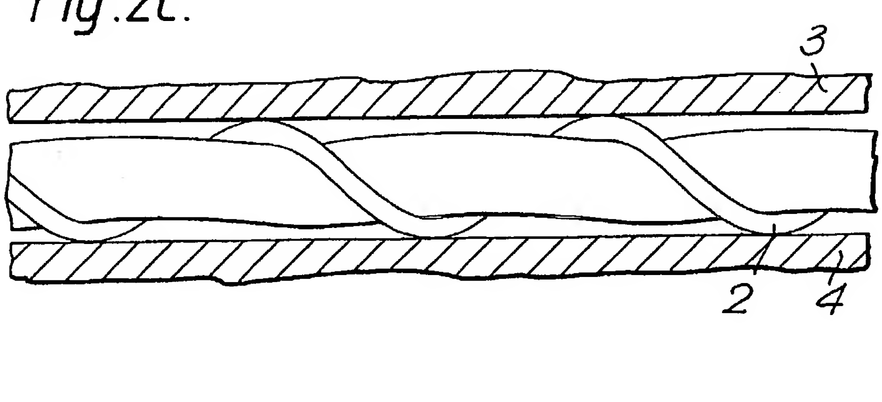


Fig.2d.

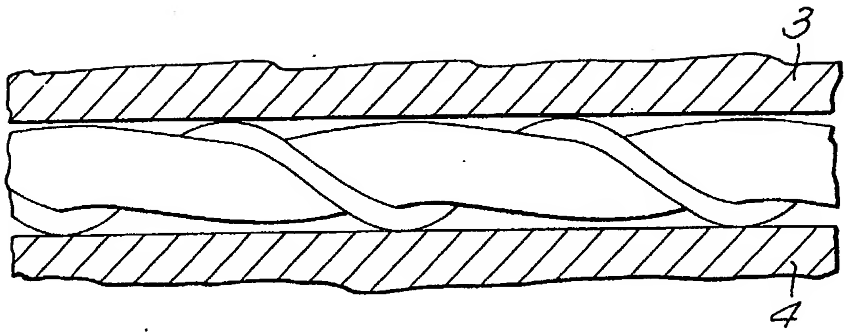


Fig.2e.

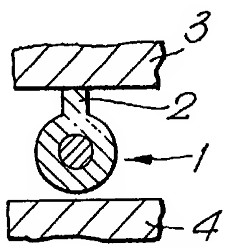


Fig.3a.

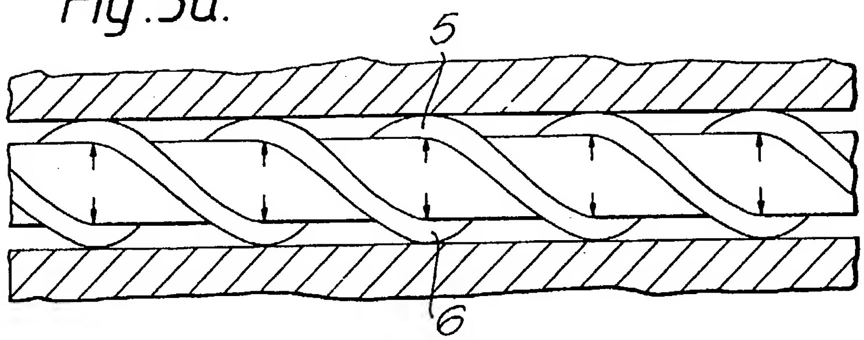
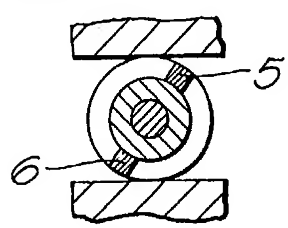


Fig.3b.



SPECIFICATION

Optical fibres

This invention relates to optical fibres and in particular to optical fibres for use in sensor systems and non-intrusive optical fibre transmission networks, and to methods of making them.

Many fibre systems make use of grating induced coupling between modes of progagation. This requires a longitudinal spatial refractive index perturbation of the optical waveguide and is typically induced by pressing a length of rigid mechanical grating against the fibre. In some applications such as a distributed optical sensor the pitch of the grating may need to be varied along the full length of the sensing fibre and various means have been proposed, see for example GB Application No. 8222371 (Serial No. 2125572B)(R.E. Epworth-V.A. Handerek 24-1), to achieve this.

According to one aspect of the present invention there is provided an optical fibre incorporating a grating structure and such that the deformation required for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the grating structure including means extending helically with respect to the length of the fibre.

According to another aspect of the present invention there is provided an optical fibre incorporating a grating structure and such that the deformation required for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the grating structure including means extending in a substantially snake-like manner with respect to the length of the fibre.

According to a further aspect of the present invention there is provided an optical fibre incorporating a grating structure and such that the deformation required for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the fibre including a core structure with a coating thereon, the coating being such that said pressure change results in a pinching-type deformation of the core structure.

According to yet another aspect of the present invention there is provided a method of manufacturing an optical fibre such that the deformation for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the method including the step of providing means extending helically with respect to the length of the fibre and comprising a grating structure for the fibre.

According to a still further aspect of the present invention there is provided a method of manufacturing an optical fibre such that optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the method including the step of providing means extending in a substantially snakelike manner with respect to the length of the fibre.

Embodiments of the invention will now be described with reference to the accompanying drawings, in which:

Fig. 1 illustrates an optical fibre with a helical rib provided on its surface;

Figs. 2a and 2b illustrates in a side view and a cross-sectional view respectively the fibre of Fig. 1 with no applied transverse pressure;

Fig. 2c illustrates a side view of the fibre of Fig. 1 with a small applied transverse pressure;

Figs. 2d and 2e illustrate a side view and a cross-sectional view respectively of the fibre of Fig. 1 with a large applied transverse pressure, and

Figs. 3a and 3b illustrate in a side view and a cross-sectional view respectively double helical ribs provided on an optical fibre, which double ribs produce pinching rather than bending of the fibre as with a single rib when transverse pressure is applied.

As mentioned above, mode coupling may be induced by pressing a fibre and a mechanical grating together. Alternatively, a periodic grating may be generated by a travelling acoustic wave excited by an electro-acoustic transducer. However, it is attractive to produce the mode coupling by merely squeezing a portion of the fibre uniformally, such as between two uniform surfaces, and this requires some form of grating structure to be associated with the fibre or rather for the fibre and the grating structure to be incorporated in an optical fibre package.

One possible method for achieving this is to incorporate the grating structure into the core structure of the fibre itself or a coating on the core structure as a helix of the same pitch as the required grating. In a fibre waveguide very little coupling occurs between two modes supported thereby unless the difference between their propagation constants is very small. When the fibre is deformed such that it undulates with a longitudinal period which matches the beat length between the two modes then efficient mode coupling takes place. The beat length is the length of fibre over which two modes slip by one wavelength with respect to each other and is inversely proportional to the difference in propagation constants. The beat length between modes varies with optical frequency, hence mode coupling only occurs at the optical frequency at which the beat length and the perturbation length are matched. The coupling

falls with reduced matching. The perturbation length is the period of the fibre undulations i.e. the grating pitch. The frequency selectivity may be maximised by employing a sufficient length for the uniform surfaces between which the fibre package is squeezed and by minimising the amplitude of the periodic deformations of the fibre.

One possible embodiment of fibre is shown in Fig. 1 which illustrates an optical fibre 1 with a grating structure incorporated into a coating thereon as a helical rib 2. A length of such a fibre is disposed between two plane surfaces 3 and 4 (Figs. 2a and 2b illustrate the arrangement with no pressure applied across the fibre). When there is applied pressure the pressure is applied to the high spots on the coating (where the surfaces 3,4 contact the rib 2) and the desired periodic stress is achieved (Fig. 2c). The greater the transverse pressure across the fibre the more the deformation (Fig. 2d and e).

The single helical rib of Figs. 1 and 2 would be used when coupling between different order modes is required, for example fundamental to first order or fundamental to a group of cladding modes, as this will result in the required "snaking" stress distribution along the fibre. The great advantage of the use of a helical member is that it avoids the need to align the axis of the periodically deformed fibre coating with the surfaces which apply the pressure for the deformation. When a conventional fibre is deformed by a mechanical grating the fibre has to be correctly aligned therewith since in effect gratings of different pitches are achieved for different angles between the fibre and the mechanical grating.

When the coupling is required between pairs of orthogonally polarised modes of the same order, for example between the two polarisation modes in birefringent "single mode" fibre, the perturbation should be applied as a periodic pinching of the fibre core as opposed to snaking thereof. This may be achieved by using a double helix that is two helical ribs 5,6 (Figs. 3a and 3b). Pinching is achieved where indicated by the arrows in Fig. 3a between opposite high spots on the coating. Birefringent fibre does have defined fast and slow axes so the sensitivity of this arrangement will vary with the relative orientation of the principal axes and the plane of the applied pressure.

As indicated above the helical grating structure may be applied either to the fibre itself or to a coating thereon. A single helix may be produced by spinning an eccentric preform e.g. with a single flat on one side, during fibre pulling. Whilst a double helix could be generated similarly from a preform with a pair of opposed flats this is not a suitable method of production for birefringent fibre, since spinning a birefringent fibre suppresses its birefringence.

The helix may be more conveniently applied to a fibre coating. It may either be a raised helical ridge (rib) as shown in the drawings or a helical depression, the only requirement being that of achieving helical eccentricity. This may be done whilst the preform is being pulled or during a subsequent operation.

Various methods may be employed to produce a grating in the coating. For example a coating nozzle through which the fibre is passing may be made to move in a circular path (circularly oscillate) with respect to the fibre. This will cause the fibre to be offset and to follow a helical path within the coating. In the case of simple side to side oscillation of the coating nozzle a simple (non-helical) grating (sinuous grating structure) will be achieved and this could be used if the grating axis was aligned with the applied pressure and it could also be used with birefringent fibre if the grating axis was aligned (45°) with the principal axes. If the fibre is much stiffer than the coating, the fibre will be essentially straight with the coating following a helical path around it. When this coated fibre is pressed between two uniform surfaces the fibre will experience the periodic stress described above with reference to Figs. 1 and 2. There will in addition be some helical deformation of the fibre but this will not interfere with the periodic stress-induced mode coupling. The pitch of the helix may be controlled and varied along the overall fibre length (as required for a distributed sensor) by setting the number of oscillatory cycles of the nozzle per unit length of pulled fibre passing through the nozzle.

An alternative approach is to emboss a previously coated fibre by heat softening and pressure deformation of the coating. For the simple (non-helical) grating the coated fibre may be passed between a pair of "cogs" which are either in mesh to produce a snaking (snake-like) deformation or teeth-to-teeth to produce a pinching deformation. A variation on this is to introduce regular nicks in the fibre coating. Axis alignment, needed if a simple (non-helical) technique is used, can be made easier by flattening the modified (coated) fibre. This could be achieved in the same rolling process, as the coating is naturally displaced to the sides. Embossing of a helix may be achieved with two pairs of similarly shaped embossing tools disposed at right angles to one another and driven in quadrature.

A pinching type deformation can also be achieved as a result of deliberately beading the coating by modulating the diameter of the coating nozzle, by modulating the vertical position of the coating nozzle (and thus the coating velocity) or by modulating the pressure of the feed to the nozzle. Alternatively the coating curing could be modulated appropriately, for example for beading modulate the bright-

ness of a curing light source, or for a helical coating rotate the point of illumination around the fibre. This modulation could be electro-optical or mechanical.

A further possibility is to helically apply (wind) an elongate element, or two elements for a double helix, around the optical fibre with the appropriate pitch for the required mode-coupling grating. Such additional elements may be of glass if hot pulled, or nylon fibre, or wire for example.

Any of the above described fibres structures may be made into a sensor by applying pressure transversely to the length of the fibre. The pressure may be achieved using parallel smooth plates, as described above, or by winding the fibre onto a deformable smooth mandrel which is expandible by air pressure, for example, and changing the applied air pressure. The technique proposed will allow a wide variety of means of applying the pressure as the axis is not critical. Alternatively changes in transverse pressure may be induced by changes in fibre tension, this resulting in a more compliant transducer. Both squeezing and stretching a fibre will result in deformation of the fibre core due to the grating structure, both producing changes in the pressure pertaining across the fibre transversely to its length.

The fibre structures may also be employed in local area networks as non-intrusive network cables, eliminating the need to apply a grating at each network node. See for example our co-pending Application No. 8526942 (Serial No.) (R.E. Epworth 33). In the case of helically extending members providing the grating structure, the grating is always aligned with the applied load whatever the orientation of the fibre, thus facilitating use of the fibre. For birefringent fibre in particular it will be advisable to provide some form of orientation indication on the fibre.

CLAIMS

1. An optical fibre incorporating a grating structure and such that the deformation required for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the grating structure including means extending helically with respect to the length of the fibre.

2. An optical fibre as claimed in claim 1, wherein the fibre includes a core structure and a coating thereon, the coating including the helically extending means.

3. An optical fibre as claimed in claim 2, wherein the coating includes a raised helical rib.

4. An optical fibre as claimed in claim 2, wherein the coating includes a helical depression.

5. An optical fibre as claimed in claim 1, wherein the fibre includes a core structure and a coating thereon, the core structure including the helically extending means.

6. An optical fibre as claimed in claim 5, wherein the core structure was drawn from an eccentric preform whilst spinning the preform.

7. An optical fibre as claimed in claim 1 wherein the fibre includes a core structure and a coating thereon, either the coating following a helical path around the core structure, or the core structure following a helical path with the coating, whereby to provide the helically extending means.

8. An optical fibre as claimed in claim 7 wherein the helical path resulted from circularly oscillating a coating nozzle through which the core structure is passed for application of said coating.

9. An optical fibre as claimed in claim 1 wherein the fibre includes a core structure and a coating thereon, the helical extending means having been provided in the coating by an embossing process.

10. An optical fibre as claimed in claim 2 wherein the coating is of a material requiring curing after application thereof and the helically extending means was provided in the coatings by rotating a curing light source around the fibre.

11. An optical fibre as claimed in claim 1 wherein the fibre includes a core structure and a coating thereon and wherein the helically extending means comprises an additional elongate element helically wound on the coated core structure.

12. An optical fibre as claimed in claim 2, the coating having been deformed by passing the fibre between two pairs of embossing tools driven in quadrature.

13. An optical fibre as claimed in claim 1 wherein the grating structure incorporates two said helically extending means whereby periodic pinching of a core of the fibre occurs when the fibre is pressed between a pair of smooth surfaces.

14. An optical fibre as claimed in claim 13 wherein the two said helically extending means are each comprised by a respective raised helical rib formed in a coating on the fibre core.

15. An optical fibre as claimed in claim 13 wherein the two said helically extending means are each comprised by a respective additional elongate element helically wound on a coating on the fibre core.

16. An optical fibre as claimed in any one of claims 13 to 15 wherein the fibre core is a birefringent fibre structure and the modes to be coupled are two polarisation modes.

17. An optical fibre as claimed in any one of the preceding claims and for use as a distributed sensor, wherein the pitch of the helically extending means varies along the length of the fibre.

18. An optical fibre incorporating a grating

structure and such that the deformation required for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the grating structure including means extending in a substantially snake-like manner with respect to the length of the fibre.

19. An optical fibre as claimed in claim 18, wherein the fibre includes a core structure with a coating thereon, the coating following a snake-like path relative to the core structure as a result of side-to-side oscillation of a coating nozzle through which the core structure is passed for application of said coating.

20. An optical fibre as claimed in claim 18, wherein the fibre includes a core structure with a coating thereon, the coating following a snake-like path relative to the core structure as a result of passing the coated fibre between a pair of cogs with meshed teeth.

21. An optical fibre as claimed in claim 18, wherein the fibre includes a core structure with a coating thereon, the coating following a snake-like path relative to the core structure as a result of introducing regular nicks in the coating.

22. An optical fibre incorporating a grating structure and such that the deformation required for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the fibre including a core structure with a coating thereon the coating being such that said pressure change results in a pinching-type deformation of the core structure.

23. An optical fibre as claimed in claim 22 the coating having been deformed by passing the fibre between a pair of toothed cogs arranged teeth to teeth whereby to produce a pinched deformation of the coating.

24. An optical fibre as claimed in claim 22 the coating being of beaded form as a result of modulating the diameter of a coating nozzle through which the fibre core is passed for application of the coating.

25. An optical fibre as claimed in claim 22 the coatings being of beaded form as a result of modulating the vertical position of a coating nozzle through which the fibre core is passed vertically for application of the coating.

26. An optical fibre as claimed in claim 22 the coating being of beaded form as a result of modulating the pressure of the feed of coating material to a coating nozzle through which the fibre is passed for application of the coating.

27. An optical fibre as claimed in claim 22, the coating being formed from a light curable material and being of beaded form as a result of modulating the brightness of a curing light source.

28. A method of manufacturing an optical fibre such that the deformation for optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the method including the step of providing means extending helically with respect to the length of the fibre and comprising a grating structure for the fibre.

29. A method as claimed in claim 28 wherein the fibre includes a core structure with a coating thereon, the helically extending means being formed of coating material.

30. A method as claimed in claim 29 wherein the coating is applied by passing the core structure through a coating nozzle and including the step of circularly oscillating the coating nozzle during application of the coating.

31. A method as claimed in claim 29, including the step of embossing the helically extending means on the coated core structure of the fibre.

32. A method as claimed in claim 28 wherein said step comprises helically wrapping an elongate element around the fibre.

33. A method as claimed in any one of claims 28 to 32 including the step of providing a further helically extending means whereby a pinching type deformation of the fibre can be achieved.

34. A method of manufacturing an optical fibre such that optical power coupling between modes can be achieved by producing changes in the pressure pertaining across the fibre transversely to its length, the method including the step of providing means extending in a substantially snake-like manner with respect to the length of the fibre.

35. A method as claimed in claim 34 wherein the fibre includes a core structure with a coating thereon, the snake-like extending means being formed of coating material.

36. A method as claimed in claim 35 wherein the coating is applied by passing the core structure through a coating nozzle and including the step of side-to-side oscillating the coating nozzle during the application of the coating.

37. A method as claimed in claim 35 including the step of embossing the snake-like extending means on the coated core structure of the fibre.

38. An optical fibre incorporating a grating structure substantially as herein described with reference to Figs. 1 and 2(a) to 2(e) or Figs. 3a and 3b of the accompanying drawings.

39. A method of manufacturing an optical fibre incorporating a grating structure substantially as herein described with reference to Figs. 1 and 2(a) to 2(e) or Figs. 3a and 3b of the accompanying drawings.

Printed for Her Majesty's Stationery Office
by Burgess & Son (Abingdon) Ltd, Dd 8991685, 1987.
Published at The Patent Office, 25 Southampton Buildings,
London, WC2A 1AY, from which copies may be obtained.